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Sunspot equilibria and the transfer paradox[★]

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Summary. We show that for international economies with two countries, in which agents have additively separable utility functions, the existence of sunspot equilibria is equivalent to the occurrence of the transfer paradox. This equivalence enables us to provide some new insights on the relation of the existence of sunspot equilibria and the multiplicity of spot market equilibria.

Keywords and Phrases: Sunspot equilibria, Transfer paradox.

JEL Classification Numbers: C62, D52, F3, F20, O12.

1 Introduction

A well known paradox in international trade theory is the so-called *transfer paradox* (cf. Leontief, 1936). This paradox is said to occur if some country donates some of its resources to some other country and yet the donor benefits while the recipient is worse off. The transfer paradox is important for example to understand the widening gap between the gross national product of less and of highly developed countries. According to this view foreign aid may be the *reason* for the disadvantageous development of the recipient country.

A well known paradox in financial economics is the so-called *sunspot paradox*. This paradox is said to occur if some exogenous event has no direct influence on the economic fundamentals and yet the endogenous equilibrium allocation depends on

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it. Sunspot equilibria are important for example to understand the phenomenon of self-fulfilling expectations which is an essential feature of financial markets.

At first sight these two paradoxes seem unrelated. The transfer paradox concerns comparative statics with respect to endowment redistributions while the sunspot paradox is a property of competitive equilibria in some given economy. The idea that these paradoxes may be related arises from the observation that both can result from the multiplicity of equilibria. However, multiplicity of equilibria is a sufficient but not a necessary condition for the paradoxes to occur and it would be useful to establish actual equivalence as this would allow the two strands of literature to be combined. The purpose of this note is to show that for a specific class of economies these two paradoxes are indeed equivalent. Hence, this note provides a link between two strands of the literature which have so far been developed in isolation.

The class of economies we consider are economies with two agents (resp. two countries) whose utility functions are concave transformations of additively separable functions. The case of two countries is the canonical international trade model and additive separability of utility functions is a commonly used assumption in applied general equilibrium theory. Applications of the general equilibrium model are usually done for a class of economies with a simple enough structure so that excess demand functions remain manageable. Computable general equilibrium models (cf. Shoven and Whalley, 1992), examples for the occurrence of the transfer paradox (Leontief, 1936; Chichilniski, 1980; Chichilniski, 1983; Rao, 1992; Geanakoplos and Heal, 1983; etc), and examples for multiple equilibria (Kehoe, 1985, 1991; Hens et al., 1999, 2002) therefore use the class of CES-utility functions. The class of utility functions assumed in this paper (concave transformations of additively separable functions) includes CES-functions. For this class of economies we show that across competitive equilibria higher levels of utility are associated with lower marginal utility. This property is important to establish the equivalence between the two paradoxes.

To get the intuition for our result note that a sunspot equilibrium consists of a set of spot market equilibria (one for each sunspot state) where the endowments of each spot market economy are obtained from redistributions resulting from the equilibrium asset market allocation. Hence an unfavorable redistribution of endowments as it occurs exogenously in the transfer paradox can be derived from asset trade only if the agent who expects a utility loss from the transfer also sees a chance of a utility gain in some other sunspot state. In the asset market equilibrium the sum across states (adjusted by the common probability beliefs) of the products of marginal utilities and wealth transfers has to be equal for both agents. The above mentioned property then allows to order marginal utilities inversely to utility levels and by the transfer paradox the order of wealth transfers does not coincide with the order of utility levels. Hence by an appropriate choice of the agents' degree of risk aversion both agents' first order conditions can be satisfied at nontrivial levels of asset trade which in turn implies that allocations differ across sunspot states. The converse of this statement is also true: If there are non-trivial sunspot equilibria, then the order crossing property just described has to hold, i.e. the transfer paradox occurs. Of course, a rigorous argument for this intuition will be given once we have made precise the setup of the model considered.

As an application of the equivalence between the transfer paradox and the sunspot paradox we show that the occurrence of sunspot equilibria is subject to the same critique as the occurrence of the transfer paradox. In a model with two commodities in each country, sunspot equilibria can only occur if the initial equilibrium (the equilibrium without asset trade) is not unique. Moreover, if as in the case of Cobb-Douglas economies, uniqueness of equilibria is guaranteed for almost all distributions of endowments then sunspot equilibria cannot occur at all. Then we show, using the equivalence between the two paradoxes, that nevertheless the occurrence of sunspot equilibria does not need to be based on the exogenous selection among multiple equilibria. We construct a simple example in which the equilibrium of any sunspot state is not an equilibrium of any other sunspot state. This example is based on the idea that financial markets may specify incomplete insurance against the uncertainty that they induce. That is to say, in this example asset payoffs are sunspot-dependent and incomplete.

The example further clarifies the relation of the existence of sunspot equilibria and the uniqueness of spot market equilibria. This question has also been addressed by Mas-Colell (1992) and Gottardi and Kajii (1999), for example. The result in this section extends the results of Mas-Colell (1992) to a stronger notion of uniqueness of spot market equilibria. As a by-product it clarifies a confusion that has recently come up in Hens (2000) and Barnett and Fisher (2002). Note also that the result of Gottardi and Kajii (1999) does not apply to our model because it relies on first period consumption. With first period consumption asset trade may occur because of intertemporal substitution and as a by-product this may introduce extrinsic uncertainty as Cass (1989) has first pointed out. Also for the same reason the technique developed by Gottardi and Kajii (1999) is not applicable here because they control the agents' utility gradients both by perturbing the utility functions and by changing the level of first-period consumption.

In the next section we outline the model and give the definitions of the transfer paradox and of sunspot equilibria. Thereafter we prove our main result establishing the equivalence of the transfer paradox and the occurrence of sunspot equilibria. Section 4 applies this result to derive some new insights both for sunspot equilibria and also for the transfer paradox. Section 5 concludes.

2 Model

We first outline the sunspot model. The transfer paradox will then be embedded in the sunspot model by a new interpretation of the sunspot states.

There are two periods. In the second period, one of $s = 1, \dots, S$, states of the world occurs. In the first period assets are traded. Consumption only takes place in the second period. This assumption is important here because otherwise the sunspot model cannot be linked to the atemporal transfer paradox model. There are $l = 1, \dots, L$, commodities in each state. Since our results hold for the case of two agents, even though it is not necessary for the general definitions, we will outright restrict attention to two agents $i = 1, 2$. States are called *sunspot states* because the agents' characteristics within the states, i.e. the agents' endowments $\omega^i \in X^i$ and their utility functions $u^i : X^i \rightarrow \mathbb{R}$, do not depend on them. X^i is a closed convex

subset of \mathbb{R}_+^L which denotes agent i 's consumption set. In the sunspot literature the agents' characteristics $[(u^i, \omega^i)_{i=1,2}]$ are called the *economic fundamentals*.

Throughout this note we make the

Assumption 1 (Additive separability) *Both agents' von Neumann-Morgenstern utility functions u^i are additively separable, i.e. $u^i(x_1^i, \dots, x_L^i) = \sum_{l=1}^L g_l^i(x_l^i)$ for all $x^i \in X^i$, where the functions g_l^i , $l = 1, \dots, L$, are assumed to be twice continuously differentiable, strictly increasing and concave. Moreover, we assume that for every agent i at least $L - 1$ of the functions g_l^i are strictly concave and that for all commodities l there is some i for which g_l^i is strictly concave.*

Note that the assumptions on the functions g_l^i guarantee strict quasi-concavity of the function u^i . The class of utility functions covered by this assumption is quite large and it includes all utility functions that are commonly used in applied general equilibrium theory. In particular, the case of CES utilities defined for all $i = 1, \dots, I$ on $X^i = \{x \in \mathbb{R}_{++}^L | u^i(x) \geq u^i(\omega^i)\}$, for some $\omega^i \in \mathbb{R}_{++}^L$, is covered by these assumptions, since then $g_l^i(x_l^i) = (\alpha_l^i)^{1-\rho^i} (x_l^i)^{\rho^i}$ for some $0 < \alpha_l^i < 1$, $l = 1, \dots, L$ and some $\rho^i < 1$.

Moreover we assume that

Assumption 2 (Expected utility) *For both agents, $i = 1, 2$, the expected utility functions, defining preferences over state contingent consumption $x^i(s) \in \mathbb{R}^L$, $s = 1, \dots, S$ are given by*

$$U^i(x^i(1), \dots, x^i(S)) = \sum_{s=1}^S \pi(s) h^i(u^i(x^i(s))) \quad \forall x^i \in (X^i)^S,$$

where the h^i are twice continuously differentiable, strictly increasing and strictly concave functions.

Hence what matters for agents' asset demand is the composition $h^i \circ u^i$, which are concave transformations of additively separable functions. Note that Assumptions 1 and 2 together are sufficient to guarantee strict quasi-concavity of the function U^i . In the first period agents can trade $j = 1, \dots, J$, real assets with payoffs $A^j(s) \in \mathbb{R}^L$ if state s occurs. We denote asset prices by $q \in \mathbb{R}^J$. Agent i 's portfolio of assets is denoted by $\theta^i \in \mathbb{R}^J$. All equilibria we consider in this setting are special cases of competitive equilibria, which are defined in

Definition 1 (Competitive equilibrium) *A competitive equilibrium is an allocation $(x^*, \theta^*)_{i=1,2}$, and a price system (p^*, q^*) such that*

1. *For both agents $i = 1, 2$:*

$$(x^*, \theta^*) \in \operatorname{argmax}_{x^i \in X^i, \theta^i \in \mathbb{R}^J} \sum_{s=1}^S \pi(s) h^i(u^i(x^i(s)))$$

$$\text{s.t. } q^* \cdot \theta^i \leq 0, p^*(s) \cdot x^i(s) \leq p^*(s) \cdot \omega^i + p^*(s) \cdot A(s) \theta^i \text{ for all } s = 1, \dots, S.$$

2. $x^1(s) + x^2(s) = \omega^1 + \omega^2$ for all $s = 1, \dots, S$.

3. $\theta^1 + \theta^2 = 0$.

Remark 1 To simplify the exposition when analyzing competitive equilibrium allocations and Pareto-efficient allocations we restrict attention to *interior* allocations, i.e. to allocations x^i in the interior of X^i , $i=1,2$. A sufficient assumption guaranteeing the interiority of allocations is to impose that the functions h^i and g_l^i satisfy the Inada condition according to which the marginal utility tends to infinity at the boundary of the consumption set $X^i \subset \mathbb{R}_+^L$.

Note that a competitive equilibrium consists of S spot market equilibria (one for each spot market economy with endowments $\hat{\omega}^i(s) = \omega^i + A(s)\theta^i$) together with an asset market equilibrium by which the ex-post endowments of the spot markets are generated. Finally, note that when showing the existence of sunspot equilibria we allow to choose the characteristics not fixed by the economic fundamentals, the sunspot extension, appropriately. The sunspot extension consist of the probabilities of the sunspot states π , the asset structure A and also the risk aversion functions h^i . The sunspot equilibria are robust with respect to perturbations of these characteristics. However sunspot equilibria will not exist for all possible choices of the sunspot extension.

It will be convenient to introduce the spot-market economy of the economic fundamentals as a point of reference. To abbreviate notations we therefore let this economy be the spot market economy in the spot $s = 0$.

In the sunspot literature agents transfer commodity bundles across sunspot states by trading assets. In the international trade literature one thinks of transfers of commodities arising from donations. Each sunspot state can then be associated with different such donations. The *transfer paradox* is said to occur if some agent donates some of his resources to the other agent and yet the donor's utility increases while the recipients utility decreases. In this statement the utility comparison is done across the competitive equilibria of the economy before and after the donation. In the standard case of the transfer paradox, the transfer was considered to be a transfer of a non-negative amount of commodities (Leontief, 1936). In order to make the equivalence to the sunspot model more obvious, we consider a slightly more general definition of the transfer paradox which only requires that the donated commodities have non-negative value in the competitive equilibrium after the transfer. As Geanakoplos and Heal (1983) have already shown this generalization is innocuous.

In the following definition we consider alternative possible transfers $\Delta\omega(z)$ that we index by some scenarios z . When relating the transfer paradox to sunspot equilibria these scenarios will be associated with different states of the world, $z = 1, \dots, S$. Taking care of potentially multiple equilibria the transfer paradox is then defined as in

Definition 2 (Transfer paradox) *Given an economy with fundamentals $[(u^i, \omega^i)_{i=1,2}]$ the transfer paradox occurs if and only if there exists some transfer of endowments (from agent 2 to agent 1), $\Delta\omega(z)$, such that for the economy $[u^1, u^2, \omega^1 + \Delta\omega(z), \omega^2 - \Delta\omega(z)]$ there exists an equilibrium $(x^{*1}(z), x^{*2}(z), p(z))$ with $p(z) \cdot \Delta\omega(z) \geq 0$ so that $u^1(x^{*1}(z)) < u^1(x^{*1}(0))$ for some equilibrium $(x^{*1}(0), x^{*2}(0), p(0))$ of the economic fundamentals, $[(u^i, \omega^i)_{i=1,2}]$, in the reference scenario without transfers, $s = 0$.*

Note that if the economic fundamentals have at least two equilibria then even without any transfers the transfer paradox occurs. Our definition covers this case because then $\Delta\omega = 0$ is already sufficient to obtain $u^1(x^*(z)) < u^1(x^*(0))$ for the two equilibria $s = 0, z$. Of course if the resulting equilibria are regular then in this case one can also find some transfers of endowments that have positive value and yet the recipients utility decreases. Making the transfer paradox a bit more paradoxical.

We will show that the occurrence of the transfer paradox is a necessary condition for sunspots to matter. To show a converse of this claim we consider the following slightly stronger notion of the transfer paradox.

Definition 3 (Strong transfer paradox) *Given an economy with fundamentals $[(u^i, \omega^i)_{i=1,2}]$ the strong transfer paradox occurs if and only if there exist some transfers of endowments (from agent 2 to agent 1), $\Delta\omega(z)$ and $\Delta\omega(\tilde{s})$ such that for the economies $[u^1, u^2, \omega^1 + \Delta\omega(s), \omega^2 - \Delta\omega(s)]$, $s = z, \tilde{s}$*

1. *there are some equilibria $(x^1(z), x^2(z), p(z)), (x^1(\tilde{s}), x^2(\tilde{s}), p(\tilde{s}))$ with $p(z) \cdot \Delta\omega(z) \geq 0$ and $p(\tilde{s}) \cdot \Delta\omega(\tilde{s}) \leq 0$ and*
2. *it holds that $u^1(x^1(z)) < u^1(x^1(\tilde{s})) < u^1(x^1(0))$ for some equilibrium $(x^1(0), x^2(0), p(0))$ of the economic fundamentals $[(u^i, \omega^i)_{i=1,2}]$, in the reference scenario without transfers, $s = 0$.*

Note, that if the economic fundamentals have at least three equilibria then by the same reason as given for the transfer paradox the strong transfer paradox occurs. Hence the existence of at least (three) two equilibria is sufficient for the (strong) transfer paradox. Of course, in regular economies we know that if there are at least two equilibria then there also are at least three equilibria (cf. Dierker, 1972). This observation indicates that in regular economies the transfer paradox and the strong transfer paradox are actually equivalent. Indeed this is true as the next proposition shows. Recall that in regular economies equilibria are well determined, i.e. in a neighborhood of regular equilibria (being defined by full rank of the Jacobian of market excess demand) there exists a smooth mapping from the exogenous parameters of the economy to the endogenous equilibrium values (cf. Debreu, 1970). In the following argument regularity needs only be required for the spot market equilibria of the economic fundamentals. This property holds generically in the set of agents' initial endowments $X^1 \times X^2$ (cf. Debreu, 1970).

Proposition 1 *Suppose all spot market equilibria of the economic fundamentals $[(u^i, \omega^i)_{i=1,2}]$ are regular. Then the transfer paradox and the strong transfer paradox are equivalent.*

Proof. The strong transfer paradox implies the transfer paradox. To establish the converse suppose that the transfer paradox holds. I.e. there exists some transfer of endowments (from agent 2 to agent 1), $\Delta\omega(z)$, such that for the economy $[u^1, u^2, \omega^1 + \Delta\omega(z), \omega^2 - \Delta\omega(z)]$ there exists an equilibrium $(x^1(z), x^2(z), p(z))$

with $\bar{p}(z) \cdot \Delta\omega(z) \geq 0$ so that $u^1(\bar{x}^1(z)) < u^1(\bar{x}^1(0))$ for some equilibrium $(\bar{x}^1(0), \bar{x}^2(0), \bar{p}(0))$ of the economic fundamentals, $s = 0$.

We need to show that there also exists some $\Delta\omega(\tilde{s})$ such that $\bar{p}(\tilde{s}) \cdot \Delta\omega(\tilde{s}) \leq 0$ and $u^1(\bar{x}^1(z)) < u^1(\bar{x}^1(\tilde{s})) < u^1(\bar{x}^1(0))$. This is of course the intuitive case in which a negatively valued transfer leads to a loss in utility. However, we need to ensure that this is the outcome in the spot market equilibrium *after* the transfer and that the utility loss is not too severe as compared to the loss in the transfer paradox case. This is ensured by the regularity of the equilibrium of the economic fundamentals from which we construct the transfer appropriately: Consider the utility gradient of agent 1, $\nabla u^1(\bar{x}^1(0))$, at the equilibrium of the economic fundamentals. Choose the transfers, $(\Delta\omega^1(\tilde{s}))$, such that $\nabla u^1(\bar{x}^1(0))(\Delta\omega^1(\tilde{s})) < 0$. By the first order condition of utility maximization in the reference situation $s = 0$ we get that this wealth transfer evaluated at the pre-transfer prices is negative, $\bar{p}(0) \cdot (\Delta\omega(\tilde{s})) < 0$. Since $\nabla u^1(\bar{x}^1(0))(\Delta\omega(\tilde{s})) < 0$, by Proposition 31.2 (ii) in Magill and Quinzii (1996) we can find some $1 \geq \alpha > 0$ such that $u^1(\bar{x}^1(0) + \alpha(\Delta\omega(\tilde{s}))) < u^1(\bar{x}^1(0))$. Moreover, by the regularity of the economy, $\alpha > 0$ can be chosen small enough so that also the utility at the induced equilibrium is smaller than in the reference situation without transfers, $u^1(\bar{x}^1(\tilde{s})) < u^1(\bar{x}^1(0))$. This is because in regular economies the induced change in the equilibrium allocation $\bar{x}^1(\tilde{s})$ can be held small so that $|u^1(\bar{x}^1(\tilde{s})) - u^1(\bar{x}^1(0) + \alpha\Delta\omega(\tilde{s}))|$ is also small. Moreover, by the same continuity argument this can be done such that $\Delta\omega^1(\tilde{s})$ evaluated at prices after the transfer is non-positive, i.e. $\bar{p}(\tilde{s}) \cdot \Delta\omega^1(\tilde{s}) \leq 0$. Finally, all this can be done without decreasing the utility level too much, so that for agent 1 we get the inequality $u^1(\bar{x}^1(z)) < u^1(\bar{x}^1(\tilde{s})) < u^1(\bar{x}^1(0))$. \square

The strong transfer paradox ensures the order crossing property mentioned in the introduction. To see this, note that it is always possible to transfer resources from agent 2 to agent 1, say $\Delta\omega(\hat{s})$, such that the transfer has negative value in the resulting equilibrium, i.e. $\bar{p}(\hat{s}) \cdot \Delta\omega(\hat{s}) \leq 0$, and agent 1 gets a level of utility that is smaller than any of the utility levels considered in the definition of the strong transfer paradox, i.e. $u^1(\bar{x}^1(\hat{s})) < u^1(\bar{x}^1(z)) < u^1(\bar{x}^1(\tilde{s})) < u^1(\bar{x}^1(0))$.¹ By this observation we get three transfers, two with negative value and one with positive value so that the utility decreases for all transfers. As we will see, by Assumption 1 on the economic fundamentals, we then get that the order of the marginal utilities does not coincide with the order or the reverse order of the transfer values, i.e. the order crossing property is obtained.

¹ Note that these losses in utility as compared to the equilibrium of the economic fundamentals do not conflict with the fact that trade is voluntary because it may be that the utility of agent 1 derived from his initial endowments is even smaller than the expected utility obtained in the spot market equilibria. Also the agent is assumed to be a price taker, i.e. he cannot enforce the equilibrium of the economic fundamentals.

3 Main result

In this section we show that under the maintained assumptions (two agents with utility functions being concave transformations of additively separable functions) the existence of sunspot equilibria is equivalent to the occurrence of the transfer paradox.

To prepare for this result we first define the agents' indirect utility function and their marginal utility of income within each state:

Let

$$v^i(s) = v^i(p(s), b^i(s)) = \max_{x^i \in X^i} \sum_{l=1}^L g_l^i(x_l^i(s)) \quad \text{s.t.} \quad p(s) \cdot x^i(s) \leq b^i(s)$$

be the *indirect utility* of agent i in state s . Since the functions g_l^i , $l = 1, \dots, L$ are concave and since at least $L - 1$ of them are strictly concave there is a unique point x^i at which the utility attains its maximum, provided that for all commodities the prices $p_l(s)$, $l = 1, \dots, L$ and the income $b^i(s)$ are positive. In our model the income $b^i(s)$ will be given by $p(s) \cdot (\omega^i + A(s) \cdot \theta^i)$. I.e., the values of the transfers are given by $r^i(s) = p(s) \cdot A(s) \cdot \theta^i$. In the analysis of the sunspot model the agents' *marginal utility of income* will be important

$$\lambda^i(s) = \partial_v h^i(v^i(s)) \partial_b v^i(p(s), b^i(s)).$$

Any competitive equilibrium induces an ordering of the agents' utilities across states, where by Pareto-efficiency the order of agent 1 is inverse to the order of agent 2. The following lemma demonstrates that under Assumption 1 for both agents the order of the marginal utilities of income are inverse to the order of their (indirect) utilities.

Lemma 1 *Without loss of generality assume that in a competitive equilibrium*

$$v^1(1) \leq v^1(2) \leq \dots \leq v^1(S).$$

Then under Assumption 1 it follows that

$$\lambda^1(1) \geq \lambda^1(2) \geq \dots \geq \lambda^1(S)$$

and that

$$\lambda^2(1) \leq \lambda^2(2) \leq \dots \leq \lambda^2(S).$$

Moreover, if $v^1(\tilde{s}) < v^1(z)$ for some $\tilde{s}, z \in \{1, \dots, S\}$ then the corresponding inequality in the marginal utilities of income is also strict.

Proof. Assume that

$$v^1(\tilde{s}) \leq v^1(z) \quad (\text{resp. that } v^1(\tilde{s}) < v^1(z)) \quad \text{for some } \tilde{s}, z \in \{1, \dots, S\}.$$

Then for some commodity, say $k \in \{1, \dots, L\}$ we must have that

$$x_k^1(\tilde{s}) \leq x_k^1(z) \quad (\text{resp. that } x_k^1(\tilde{s}) < x_k^1(z)).$$

Moreover, Pareto-efficiency within spot markets implies that for all states $s = 1, \dots, S$ the marginal rates of substitution are equal across agents, i.e.

$$\frac{\partial g_m^1(x_m^1(s))}{\partial g_l^1(x_l^1(s))} = \frac{\partial g_m^2(x_m^2(s))}{\partial g_l^2(x_l^2(s))}$$

for any pair of commodities (l, m) . Note that $x_m^2(s) = \omega_m^1 + \omega_m^2 - x_m^1(s)$, $s = 1, \dots, S$. Hence if the functions g_l^i are concave and if for some agent the function g_l^i is strictly concave then it follows that

$$x_l^1(\tilde{s}) \leq x_l^1(z) \quad (\text{resp. that } x_l^1(\tilde{s}) < x_l^1(z)) \quad \text{for all } l = 1, \dots, L.$$

Without loss of generality assume that $l = n$ is the numeraire in all states $s = 1, \dots, S$, where n is chosen such that g_n^1 is strictly concave. Hence we have shown that

$$v^1(1) \leq v^1(2) \leq \dots \leq v^1(S) \quad (\text{with } v^1(\tilde{s}) < v^1(z) \quad \text{for some } \tilde{s}, z)$$

implies for the numeraire that

$$x_n^1(1) \leq x_n^1(2) \leq \dots \leq x_n^1(S) \quad (\text{with } x_n^1(\tilde{s}) < x_n^1(z) \quad \text{for some } \tilde{s}, z).$$

From the first order condition to the maximization problem

$$\max_{x^i \in X^i} u^1(x^1(s)) \quad \text{s.t.} \quad p(s) \cdot x^1(s) \leq b^1(s)$$

we get that $\partial_b v^1(p(s), b^1(s)) = \partial g_n^1(x_n^1(s))$ for all $s = 1, \dots, S$. Since h^1 and g_n^1 are strictly concave and since $x_n^1(s)$ and $v^1(s)$ are increasing (resp. strictly increasing) in s we get that

$$\lambda^1(1) \geq \lambda^1(2) \geq \dots \geq \lambda^1(S) \quad (\text{resp. that } \lambda^1(z) > \lambda^1(\tilde{s})).$$

The claim for $i = 2$ follows analogously from the inverse inequalities

$$x_l^2(1) \geq x_l^2(2) \geq \dots \geq x_l^2(S), \quad \text{for all } l = 1, \dots, L,$$

and from

$$v^2(1) \geq v^2(2) \geq \dots \geq v^2(S),$$

the latter inequalities being implied by Pareto-efficiency within spot markets. \square

This lemma puts us now in the position to prove the equivalence of the occurrence of the transfer paradox and the existence of sunspot equilibria.

Theorem 3 (Main result) *Suppose both agents' utility functions are concave transformations of additively separable functions (Assumption 1 and Assumption 2). Then*

1. *the transfer paradox is a necessary condition for sunspots to matter and*
2. *the strong transfer paradox is a sufficient condition for sunspots to matter.*

Proof.

1. To link the transfer paradox to the sunspot economy consider

$$r(s) := \bar{p}^*(s) \cdot A(s)\theta^1,$$

i.e. the transfer of income from agent 2 to agent 1 as generated by asset trade in some competitive equilibrium.

A necessary condition for optimal portfolio choice is

$$\sum_{s=1}^S \lambda^i(s) \pi(s) r(s) = 0, i = 1, 2,$$

which we call the first-order conditions for asset demand.²

Without loss of generality assume that

$$v^1(1) \leq v^1(2) \leq \dots \leq v^1(S),$$

which by Pareto-efficiency within spot markets implies

$$v^2(1) \geq v^2(2) \geq \dots \geq v^2(S).$$

Now suppose, the transfer paradox does not occur. Then from the observation made above it follows that the economic fundamentals must have a unique equilibrium and for all states $s = 1, \dots, S$, $r(s) \geq 0$ is equivalent to $v^1(s) \geq v^1(0)$ and $v^2(s) \leq v^2(0)$. Accordingly $r(s) \leq 0$ is equivalent to $v^1(s) \leq v^1(0)$ and $v^2(s) \geq v^2(0)$. As above $s = 0$ is the index of the reference economy given by the economic fundamentals.

Let \bar{s} be such that $r(s) \leq 0$ for all $s \leq \bar{s}$ and $r(s) \geq 0$ for all $s > \bar{s}$, then the first-order conditions for asset demand imply that

$$\sum_{s \leq \bar{s}} (\lambda^1(s) - \lambda^2(s)) \pi(s) |r(s)| = \sum_{s > \bar{s}} (\lambda^1(s) - \lambda^2(s)) \pi(s) |r(s)|.$$

The expected utility functions U^i are invariant with respect to positive affine transformations of the utility functions $h^i \circ u^i$. Hence without loss of generality we can choose the functions h^i such that for the economy in \bar{s} we have $\lambda^i(\bar{s}) = 1$, for $i = 1, 2$.

Moreover, given this normalization, from the lemma proven above we know that the differences $(\lambda^1(s) - \lambda^2(s))$ are non-negative for $s \leq \bar{s}$ and they are non-positive for $s > \bar{s}$.

Hence, if sunspots did matter, then at least one of these differences together with the corresponding $r(s)$ has to be non-zero, which contradicts the derived equality.

2. Suppose the strong transfer paradox occurs, then there exist transfers indexed by \tilde{s} , z such that

$$r(z) \geq 0, r(\tilde{s}) \leq 0 \quad \text{and for some equilibria} \quad v^1(z) < v^1(\tilde{s}) < v^1(0)$$

² This condition follows from $\sum_s \lambda^i(s) \pi(s) p(s) A(s) = \gamma^i q$ together with $q \cdot \theta^i = 0$, $i=1,2$.

where $v^1(0)$ refers to agent 1's utility in an equilibrium of the spot economy $s = 0$.

Given the utility functions u^1, u^2 and given the total endowments $\omega^1 + \omega^2$ consider the set of Pareto-efficient allocations as being parameterized by the income transfers r .

Now we have to distinguish three cases:

Case 1: If $r(z) > 0$

then we know that $b^1(z) > 0$ and therefore there exists $r(\hat{s}) < 0$ sufficiently close to zero such that for the induced $b^1(\hat{s}) = (b^1(z) + r(\hat{s})) \geq 0$ we get $v^1(\hat{s}) < v^1(z)$ for some equilibrium in \hat{s} . By this observation and the strong transfer paradox we have the order crossing property:

$$r(\hat{s}) \leq 0, r(\tilde{s}) \leq 0, r(z) > 0$$

while

$$v^1(\hat{s}) < v^1(z) < v^1(\tilde{s})$$

so that by Lemma 1

$$\lambda^1(\hat{s}) > \lambda^1(z) > \lambda^1(\tilde{s})$$

To construct the sunspot equilibrium consider an economy with the three states $s = \hat{s}, \tilde{s}, z$. In this case the first-order conditions for asset demand become:

$$\lambda^i(\hat{s})\pi(\hat{s})|r(\hat{s})| + \lambda^i(\tilde{s})\pi(\tilde{s})|r(\tilde{s})| = \lambda^i(z)\pi(z)|r(z)|, i = 1, 2.$$

Now choose $\pi(z) < 1$ sufficiently large (and accordingly $\pi(\hat{s}) > 0$ and $\pi(\tilde{s}) > 0$ sufficiently small) such that

$$\pi(\hat{s})|r(\hat{s})| + \pi(\tilde{s})|r(\tilde{s})| < \pi(z)|r(z)|.$$

Note that ∂h^i is any continuous, positive and decreasing function. Recall that, $\lambda^1(\tilde{s}) < \lambda^1(z)$ and that $v^1(\hat{s})$ is the smallest utility level in the three states. Hence we can choose h^1 such that $\lambda^1(\hat{s})$ is sufficiently large to solve the first order condition for $i = 1$. Analogously it follows that $\lambda^2(\hat{s}) < \lambda^2(z)$ and we can choose h^2 such that $\lambda^2(\tilde{s})$ is sufficiently large to solve the first order condition for $i = 2$.

To complete the proof we follow the analogous steps as in Mas-Colell (1992). Choose $A \in \mathbb{R}^{3L \times 2}$ such that

$$r(s) = p(s) \cdot (A^1(s) - A^2(s)) \quad \text{for } s = \tilde{s}, \hat{s}, z. \quad (1)$$

Finally, note that

$$\sum_s \lambda^1(s)\pi(s)p(s) \cdot A^1(s) = \sum_s \lambda^1(s)\pi(s)p(s) \cdot A^2(s)$$

so that we can choose $q_1 = q_2$. Accordingly we choose $\theta^1 = (1, -1)$, $\theta^2 = (-1, 1)$ so that $q \cdot \theta^i = 0$, $i = 1, 2$ and $\theta^1 + \theta^2 = 0$. Since we have chosen an economy with two assets, the first-order conditions for asset trade are equivalent to the conditions $\sum_s \lambda^i(s)\pi(s)p(s)A(s) = \gamma^i q$.

Case 2: If $r(z) = 0$ and $r(\tilde{s}) = 0$

then by the strong transfer paradox, even without trading any asset, there is a competitive equilibrium in which sunspots matter.

Case 3: Finally, the case $r(z) = 0$ and $r(\tilde{s}) < 0$

is already covered by the reasoning of the first case if one changes the point of view from agent 1 to agent 2. \square

Remark 2 Note that in the theorem above, Part 1 has been shown for the most general statement without evoking any particular assumption on the asset structure $A \in \mathbb{R}^{S \times J}$. Part 2 however is a stronger claim the more the set of asset structures is restricted. The choice of the asset structure matters in equation (1) of the proof. One way of restricting A is to only consider numeraire assets so that all assets pay off in the same commodity. Allowing for sunspot dependent assets this is a possible choice in the solution of equation (1). If assets are not allowed to depend on the sunspot states then one can still find an asset structure solving equation (1), provided the three price vectors $p(s)$, $s = \tilde{s}, \hat{s}, z$ are linearly independent. The latter then requires to have at least 3 commodities.

Before passing to the next section we want to point out that the assumptions of additive separability is indeed tight. The inverse association between the levels of marginal utilities and that of utilities, as shown in Lemma 1 does not necessarily hold without additive separability. As the following example shows without additive separability one can find that lower utilities are associated with lower marginal utilities. The endowments in this example are supposed to be the ex-post endowments. Hence they are allowed to depend on the sunspot states since the asset payoffs may depend on them.

Remark 3 Consider a two-agent economy with two commodities. The utility functions are:

$$u^1(x^1) = \sqrt{x_1^1 x_2^1} + x_2^1 \quad \text{and} \quad u^2(x^2) = \sqrt{x_1^2 x_2^2} + x_1^2.$$

Note that neither of the two utility functions is additively separable but both are strictly monotonically increasing and strictly concave on \mathbb{R}_{++}^2 and both satisfy the Inada-conditions. Moreover, note that both utility functions are homogenous of degree one implying that both goods are normal. In situation $s = 1$ the ex-post endowments are

$$\hat{\omega}_1^1(1) = 1, \hat{\omega}_2^1(1) = 5 \quad \text{and} \quad \hat{\omega}_1^2(1) = 4, \hat{\omega}_2^2(1) = 2.$$

There is a unique equilibrium³ with prices $p(1) = (1, 0.7125)$. The equilibrium budgets are:

$$b^1(1) = 4.5623 \quad \text{and} \quad b^2(1) = 5.4249.$$

³ All values have been rounded to 4 decimal digits. The exact values can be found at the page <http://www.iew.unizh.ch/home/hens>. Uniqueness can be seen from the graph of the excess demand also shown on the webpage.

The resulting allocation is:

$$x_1^1(1) = 0.5380, x_2^1(1) = 5.6485 \quad \text{and} \quad x_1^2(1) = 4.4620, x_2^2(1) = 1.3515.$$

The utility levels are:

$$u^1(1) = 7.3917 \quad \text{and} \quad u^2(1) = 6.9177.$$

Marginal utilities within state 1, $\left(\partial_b v^i(1) = \frac{v^i(1)}{b^i(1)}\right)_{i=1,2}$, are:

$$\partial_b v^1(1) = 1.6202 \quad \text{and} \quad \partial_b v^2(1) = 1.2752.$$

Now consider a second situation $s = 2$ with the same total endowments but with a distribution of ex-post endowments as:

$$\hat{\omega}_1^1(2) = 5, \hat{\omega}_2^1(2) = 5 \quad \text{and} \quad \hat{\omega}_1^2(2) = 0, \hat{\omega}_2^2(2) = 2.$$

Again, there is a unique equilibrium, now with prices $p(2) = (1, 1.5113)$. The equilibrium budgets are:

$$b^1(2) = 12.5563 \quad \text{and} \quad b^2(2) = 3.0225.$$

The resulting allocation is:

$$x_1^1(2) = 2.3164, x_2^1(2) = 6.7758 \quad \text{and} \quad x_1^2(2) = 2.6836, x_2^2(2) = 0.2242.$$

The utility levels are:

$$u^1(2) = 10.7375 \quad \text{and} \quad u^2(2) = 3.4594.$$

Marginal utilities within state 2 are:

$$\partial_b v^1(2) = 0.8552 \quad \text{and} \quad \partial_b v^2(2) = 1.1445.$$

Note that the second agent's utility **and** his marginal utility has decreased in passing from situation 1 to situation 2. Finally, note that we can find two strictly concave functions h^i such that the same ordering still holds for the marginal utilities $\lambda^i(s) = \partial_v h^i(v^i) \partial_b v^i(s)$.

Remark 4 With more than two agents the occurrence of the transfer paradox still requires the existence of sunspot equilibria provided marginal utilities are ordered inversely to utility levels. Even for additively separable utilities this ordering property may however not hold with more than two agents. Moreover, with more than two agents the strong transfer paradox is no longer sufficient for the existence of sunspot equilibria. The simple reason is that for agent 1 the strong transfer paradox may occur while the two other agents will not find income transfers of opposite sign. The case of more than two agents is analyzed in the discussion paper Hens et al. (2004).

4 Application

Having established the equivalence between the transfer paradox and the sunspot paradox we now derive some new results on the existence of sunspot equilibria and also on the possibility of the transfer paradox. Applying Trannoy (1986) we can rule out sunspot equilibria if for all spot market economies that are induced by the wealth transfers there is a unique equilibrium. Moreover, applying Balasko (1978) we can rule out sunspot equilibria in the case of two commodities if the economic fundamentals do have a unique equilibrium. Finally, using the established equivalence we show that sunspot equilibria need not be derived from multiple equilibria of the spot market economy that is obtained by asset trade leading to the same endowment distribution in all states.

The issue we want to clarify by these results is the relation of the existence of sunspot equilibria and the uniqueness of spot market equilibria. This question has also been addressed by Mas-Colell (1992) and Gottardi and Kajii (1999), for example. The result in this section extends the results of Mas-Colell (1992) to a stronger notion of uniqueness of spot market equilibria. The result of Gottardi and Kajii (1999) is not applicable to our model because it relies on first period consumption⁴.

For that purpose the following terminology is quite useful. Ever since Cass and Shell (1983) it is now standard to say that *sunspots matter* if the allocation of the competitive equilibrium depends on the sunspot states, in which case the competitive equilibrium is called a *sunspot equilibrium*. In a sunspot equilibrium sunspots matter because by strict concavity of the expected utility functions sunspot equilibria are not ex-ante Pareto-efficient. A *randomization equilibrium* is a competitive equilibrium in which for some ex-post endowments the equilibrium allocation in every state s is a spot market allocation for the same economy. If, for example, the economic fundamentals allow for multiple equilibria then there is a randomization equilibrium. Mas-Colell (1992) has shown that with more than two commodities there can also be randomization equilibria if there are multiple equilibria for *some* distribution of endowments that is attainable via asset trade. In both cases the equilibrium allocation of such a competitive equilibrium is a randomization among the set of equilibria of *some* underlying economy. In randomization equilibria sunspots are a device to coordinate agents' expectations. This case of sunspot equilibria has found many applications. In the international trade literature, for example, currency crises are modelled by randomization sunspot equilibria. See, for example, the seminal papers by Obstfeld (1994) and Obstfeld (1996) and also the interesting empirical papers on this issue by Jeanne (1997) and Jeanne (2000).

The question that arises from these observations is whether sunspot equilibria could be identified with randomization equilibria. This would then make them very similar to publicly correlated equilibria known in the game theoretic literature

⁴ The technique used in Gottardi and Kajii (1999) is not easily applicable either because they control the agents utility gradients both by perturbing the utility functions and by changing the level of first-period consumption.

(Aumann, 1974)⁵. Hence, the results of this literature would then be applicable to sunspot equilibria.

It is obvious that in our setting with sun-independent assets, i.e. when $A(s) = A(1)$, $s = 1, \dots, S$, sunspot equilibria necessarily are randomization equilibria. It is, however, not obvious at all whether with a general asset structure there can also be sunspot equilibria which are different from randomization equilibria. To clarify this point some more definitions are needed.

Definition 4 (Attainable endowment distributions) *Given the economic fundamentals $[(u^i, \omega^i)_{i=1,2}]$ and given the asset structure A the endowment distribution $\hat{\omega}^i(s)$, $s = 1, \dots, S$, $i = 1, 2$ is attainable if there exists some competitive equilibrium with asset allocation $(\theta^*)_{i=1,2}$, such that $\hat{\omega}^i(s) = \omega^i + A(s)\theta^*$, $s = 1, \dots, S$, $i = 1, 2$.*

Based on the attainability concept we now define the uniqueness concept suggested in Mas-Colell (1992). This condition has later been called *no potential multiplicity* by Gottardi and Kajii (1999).

Definition 5 (Strong uniqueness) *The economy with the fundamentals $[(u^i, \omega^i)_{i=1,2}]$ satisfies the strong uniqueness property for some asset structure A , if the spot market equilibria are unique for every attainable endowment distribution.*

Remark 5 In the model of this note markets are *intrinsically complete*, i.e. Pareto-efficient allocations can be attained even without asset trade. With intrinsically incomplete markets sunspots are known to matter even if the economic fundamentals satisfy the strong uniqueness property [cf. Cass (1989) and the literature that has emerged from it, Guesnerie and Laffont (1988) and Gottardi and Kajii (1999)].

In our setting with intrinsically complete markets we can derive the following results:

Corollary 1 *Under the maintained assumptions, sunspots do not matter if the strong uniqueness property holds for all distributions of endowments in the Edgeworth-Box.*

Proof. Suppose sunspots do matter, then from our main result we know that the transfer paradox needs to occur. However, as Trannoy (1986) has shown, this requires to be able to trade to some distribution of endowments in the Edgeworth-Box for which there are multiple equilibria, which is a violation of the strong uniqueness property. \square

Corollary 2 *Under the maintained assumptions, in the case of two commodities sunspots do not matter if the economic fundamentals have a unique equilibrium.*

Proof. Suppose sunspots did matter then from our main result we know that the transfer paradox needs to occur. However, as for example Balasko (1978)⁶ has

⁵ See Forges and Peck (1995) for relating sunspot equilibria to correlated equilibria in an overlapping generations model.

⁶ See also the solution to exercise 15.B.10^C from Mas-Colell, Whinston and Green (1995) that is given in Hara et al. (1997).

shown, in the case of two commodities this requires to have multiple equilibria for the initial distributions of endowments. \square

From Corollary 2 we can see that in the case of two commodities and sun-independent assets it is not possible to "trade from uniqueness to multiplicity". This is because with sun-independent assets sunspots can only matter at distributions of endowments for which there are multiple equilibria. Hens (2000) has claimed that for an economy with two agents and two commodities in which utility functions are concave transformations of Cobb-Douglas utility functions sunspots matter. Corollary 2 shows that this claim is incorrect. Moreover the mistake in Hens (2000) cannot be cured by changing the values of the parameters for the same example⁷ because that example falls into the class of economies which are covered by this note. Indeed for Cobb-Douglas economies the equilibrium at the initial distribution of endowments is unique and the strong uniqueness requirement is satisfied for almost all asset structures A .

Corollary 3 shows that as in the case of intrinsically incomplete markets also with intrinsically complete markets sunspots can still matter even if they do not serve as a coordination device among multiple equilibria.

Corollary 3 *Under the maintained assumptions, even for the case of two commodities, there are sunspot equilibria which are not randomization equilibria.*

Proof. The example we give to prove this corollary is adapted from the Example 15.B.2 in Mas-Colell, Whinston and Green (1995)⁸. There are two commodities and two agents with endowments $[(\omega_1^1, \omega_2^1), (\omega_1^2, \omega_2^2)] = [(2, r), (r, 2)]$. Consumption sets are $X^i = \{x \in \mathbb{R}_{++}^L | u^i(x) \geq u^i(\omega^i)\}$ and utility functions are given by

$$u^1(x^1) = x_1^1 - \frac{1}{8}(x_2^1)^{-8} \quad \text{and} \quad u^2(x^2) = -\frac{1}{8}(x_1^2)^{-8} + x_2^2.$$

Aggregate endowments are $\omega = (2 + r, 2 + r)$ where $r = 2^{\frac{8}{9}} - 2^{\frac{1}{9}} \approx 0.77$. Figure 1 shows the Edgeworth Box of this economy.⁹

The convex curve is the set of Pareto-efficient allocations that lie in the interior of the Edgeworth Box. It is given by the function $x_2^1 = \frac{1}{2+r-x_1^1}$. The competitive equilibrium allocations of our example will be constructed out of these interior allocations. In Figure 1 we have also drawn some budget lines indexed by $s = \hat{s}, z, \tilde{s}, 0$, supporting four different Pareto-efficient allocations which are equilibrium allocations in the spot markets once appropriate spot market endowments have been chosen. The sunspot equilibrium we construct exploits the fact that in this example there are three equilibria for the distribution of endowments $[(\omega_1^1, \omega_2^1), (\omega_1^2, \omega_2^2)] = [(2, r), (r, 2)]$. Taking these endowments as the reference

⁷ This possibility is left open by the observation of Barnett and Fisher (2002) who demonstrate that for the specific parameter values chosen in Hens (2000) sunspots do not matter! Moreover, in the example they suggest instead, sunspots do not matter because agents are risk neutral.

⁸ See Hara et al. (1997) for the solution to the original example.

⁹ The Figures 1 and 2 have been generated with *MATLAB*®. The scripts can be downloaded from the page <http://www.iew.unizh.ch/home/hens>.

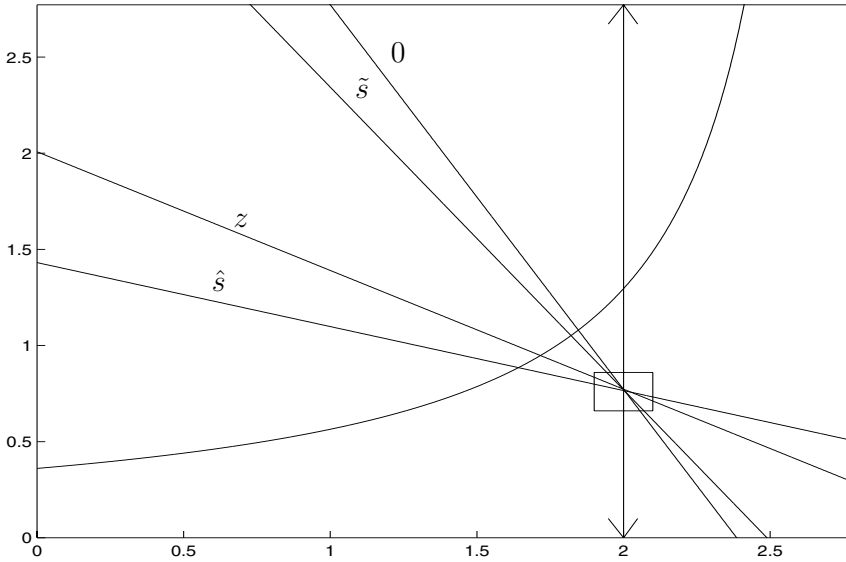


Figure 1. Edgeworth-box

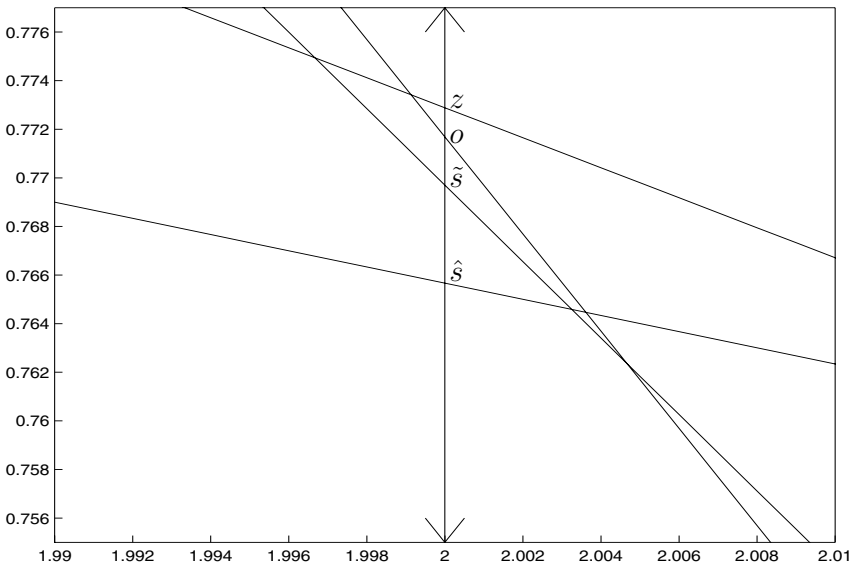


Figure 2. Zoom of the rectangle in Figure 1

point for the economy $s = 0$, we consider the transfer of endowments as visualized in Figure 2. From the three equilibria at $[(2, r), (r, 2)]$ we have chosen the one with the highest first agent utility to be the equilibrium allocation for the reference situation $s = 0$.

The asset structure A consists of numeraire assets denominated in the second commodity. The vertical line in Figure 2 indicates the possible direction of en-

dowment redistributions. With reference to $s = 0$, in the situation z the first agent has received a transfer of the second commodity but his utility decreases. In the situations \hat{s} , \tilde{s} the first agent has donated some of the second commodity and with reference to $s = 0$ his utility decreases. While in \hat{s} it falls to the lowest of the four values, in \tilde{s} it obtains a value between the utility in $s = 0$ and $s = z$. Hence for these transfers the strong transfer paradox occurs and by application of our main result there exists a sunspot equilibrium with spot market endowments given by the intersection of the budget lines \hat{s} , z , and \tilde{s} with the vertical line through the point $(2, 0)$, while the selected equilibrium in reference economy has the budget line 0.

Although this sunspot equilibrium lies in a neighborhood of a randomization equilibrium it is itself *not* a randomization equilibrium because all spot market endowments differ. \square

This example exploits the multiplicity of equilibria of the economic fundamentals in the sense that in the neighborhood of the endowment distribution leading to multiple equilibria the budget lines have various slopes that are not ordered as the utility levels resulting in the ex post spot market equilibria (see Figs. 1 and 2). This property could however also occur with a unique equilibrium for the economic fundamentals. Imagine for example that the area in the rectangle of Figure 1 would lie outside the Edgeworth-Box. Then keeping the line along which the transfers are defined inside the Edgeworth-Box the same construction could be done. Unfortunately, we could however give no simple utility functions as in Example 15.B.2 in Mas-Colell, Whinston and Green (1995) which would lead to this feature. Hence, it remains a conjecture whether there exist non-randomization sunspot equilibria even if the economic fundamentals have a unique equilibrium¹⁰.

5 Conclusion

We have shown that for international economies with two countries in which agents have additively separable utility functions the existence of sunspot equilibria is equivalent to the occurrence of the transfer paradox. Based on this result, we derived some new conditions for the occurrence of the transfer paradox and also for the existence of sunspot equilibria. In particular we established some new insights on the relation of the existence of sunspot equilibria and the multiplicity of equilibria. While the new results are shown for frictionless two period economies with incomplete markets, exploring the connection between sunspot equilibria and the transfer paradox, future research might also show interesting new results in related settings. For example one could try to get new insights for the sunspot literature by exploring the results on the transfer paradox in the overlapping generations model (Galor and Polemarchakis, 1987). And similarly there might be new results in storage analyzing economies with transaction costs respectively tariffs (Lahiri and Raimondos, 1995).

¹⁰ Note that in Mas-Colell (1992) it is not shown that for the initial distribution of endowments the equilibrium is unique.

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